(g) mol NH_4Cl = mol NH_4^+ = 0.02500 L × 6.50 mol/L = 0.162

$$\text{mol } NH_3 = 0.162 \text{ mol } NH_4^+ \times \frac{1 \text{ mol } NH_3}{1 \text{ mol } NH_4^+} = 0.162$$

mol NaOH = mol OH^- = 0.04500 L × 0.432 mol/L = 0.0194

$$\text{mol } NH_3 = 0.0194 \text{ mol } OH^- \times \frac{1 \text{ mol } NH_3}{1 \text{ mol } OH^-} = 0.0194$$

OH^- is limiting and 0.0194 mol of NH_3 are formed

$$V_{NH_3} = \frac{0.0194 \text{ mol} \times 0.0821 \text{ L} \cdot \text{atm/mol} \cdot \text{K} \times 298 \text{ K}}{745 \text{ mm Hg}(1 \text{ atm}/760 \text{ mm Hg})} = 0.485 \text{ L}$$

(h) $$\text{mol } NH_3 \text{ bubbled into } H_2O = \frac{0.845 \text{ L} \times 1.00 \text{ atm}}{0.0821 \text{ L} \cdot \text{atm/mol} \cdot \text{K} \times 300 \text{ K}} = 0.0343$$

$$M = \frac{0.0343 \text{ mol}}{4.32 \text{ L}} = 7.94 \times 10^{-3}$$

(i) $$\frac{\text{rate}_{NH_3}}{\text{rate}_{N_2}} = \left(\frac{MM_{N_2}}{MM_{NH_3}}\right)^{1/2} = \left(\frac{28.02}{17.03}\right)^{1/2} = 1.28; \qquad \frac{\text{time}_{NH_3}}{\text{time}_{N_2}} = \left(\frac{MM_{NH_3}}{MM_{N_2}}\right)^{1/2} = \left(\frac{17.03}{28.02}\right)^{1/2} = 0.780$$

(j) $$\frac{\text{rate}_{NH_3}}{\text{rate}_{N_2}} = 1.28; \qquad \text{rate}_{NH_3} = 1.28(515 \text{ m/s}) = 659 \text{ m/s}$$

PROBLEMS

1. $$V = 10.00 \text{ gal} \times \frac{4 \text{ qt}}{1 \text{ gal}} \times \frac{1 \text{ L}}{1.057 \text{ qt}} = 37.84 \text{ L}$$

   mass = (1.243 mol)(16.04 g/mol) = 19.94 g

   $$t°C = \frac{74° - 32°}{1.8} = 23°C; \quad T(K) = 273.15 + 23 = 296 \text{ K}$$

3.

mm Hg	atm	kPa	bar
396	0.521	52.8	0.528
874	1.15	116	1.16
728	0.959	97.1	0.971
7.50×10^2	0.987	1.00×10^2	1.00

5. $$\frac{V_2}{V_1} = \frac{n_2}{n_1}; \quad n_2 = \frac{3.0 \text{ mol} \times 12.1 \text{ L}}{12.6 \text{ L}} = 2.9 \text{ mol } O_2 \text{ after leaking}; \quad (3.0 - 2.9) \text{ mol} = 0.1 \text{ mol } O_2 \text{ lost}$$

7. (a) $$\frac{V_1}{V_2} = \frac{(22 + 273) \text{ K}}{(44 + 273) \text{ K}} = 0.931$$ (b) $$\frac{V_1}{V_2} = \frac{T_1}{2\,T_1} = 0.500$$

9. $$P_2 = P_1 \times \frac{T_2}{T_1} = 22.7 \text{ psi} \times \frac{266 \text{ K}}{298 \text{ K}} = 20.3 \text{ psi}; \quad \text{gauge pressure} = 20.3 \text{ psi} - 14.7 \text{ psi} = 5.6 \text{ psi}$$

11. $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$; $\frac{4.65\text{ atm} \times 38.0\text{ L}}{308\text{ K}} = \frac{P_2 \times 55.0\text{ L}}{277\text{ K}}$; $P_2 = 2.89$ atm

13. $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$; $\frac{0.998\text{ atm} \times 1.28 \times 10^3\text{ L}}{304\text{ K}} = \frac{0.753\text{ atm} \times V_2}{248\text{ K}}$; $V_2 = 1.38 \times 10^3$ L

15. mass of alcohol = (120 mL)(0.789 g/mL) = 95 g; mol alcohol = (95 g)/(46.07 g/mol) = 2.1

$$P = \frac{2.1\text{ mol} \times 0.0821\ \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 373\text{ K}}{2.00\text{ L}} = 32\text{ atm};\quad \text{it explodes!}$$

17. mol CO_2 = (22.50 g)/(44.01 g/mol) = 0.5112 ; $P = \frac{0.5112\text{ mol} \times 0.0821\ \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 296\text{ K}}{2.50\text{ L}} = 4.52$ atm

19. MM = (28.02 + 64.00) g/mol = 92.02 g/mol

P	V	T	n	m
1.77 atm	4.98 L	43.1°C	0.340 mol	31.3 g
673 mm Hg	488 mL	6.72 K	0.783 mol	72.1 g
0.899 bar	7.44 L	912°C	0.0679 mol	6.25 g
3.28 atm	1.15 L	39°F	0.166 mol	15.3 g

21. $n = \frac{(1.33\text{ bar} \times 1\text{ atm}/1.013\text{ bar}) \times 1.00\text{ L}}{297\text{ K} \times 0.0821\ \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}}} = 0.0538$ mol

density of Ar = (0.0538 mol/L)(39.95 g/mol) = 2.15 g/L

density of NH_3 = (0.0538 mol/L)(17.02 g/mol) = 0.916 g/L

density of C_2H_2 = (0.0538 mol/L)(26.04 g/mol) = 1.40 g/L

23. (a) $n = \frac{(770\text{ mm Hg} \times 1\text{ atm}/760\text{ mm Hg})(1.00\text{L})}{298\text{ K} \times 0.0821\text{ L} \cdot \text{atm}/\text{mol} \cdot \text{K}} = 0.0414$ mol

density of air = (0.0414 mol/L)(29.09 g/mol) = 1.20 g/L

(b) density of He = (0.0414 mol/L)(4.003 g/mol) = 0.166 g/L

(c) density of CO_2 = (0.0414 mol/L)(44.01 g/mol) = 1.82 g/L

density of CO_2 $>$ density of air; balloon will not rise

25. (a) $n = \frac{(755\text{ mm Hg} \times 1\text{ atm}/760\text{ mm Hg})(1.00\text{L})}{298\text{ K} \times 0.0821\text{ L} \cdot \text{atm}/\text{mol} \cdot \text{K}} = 0.0406$ mol

$\text{MM} = \frac{1.71\text{ g/L}}{0.0406\text{ mol/L}} = 42.1$ g/mol

(b) mol C = $\frac{(85.7/100)(42.1\text{ g})}{12.01\text{ g/mol}}$ = 3; mol H = $\frac{(100.0 - 85.7/100)(42.1\text{ g})}{2.016\text{ g/mol}}$ = 6; C_3H_6

27. (a) MM = 0.11(44.0 g/mol) + (0.053)(28.02 g/mol) + (0.84)(4.00 g/mol) = 9.7 g/mol

(b) $n = \frac{(758\text{ mm Hg} \times 1\text{ atm}/760\text{ mm Hg})(1.00\text{L})}{305\text{ K} \times 0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K}}$ = 0.0398 mol; d_{gas} = (0.0398 mol/L)(9.7 g/mol) = 0.39 g/L

(c) d_{air} = (0.0398 mol/L)(29.0 g/mol) = 1.15 g/L; d_{gas}/d_{air} = (0.39 g/L)/(1.15 g/L) = 0.34

29. $n = \frac{(769\text{ mm Hg} \times 1\text{ atm}/760\text{ mm Hg})(0.297\text{ L})}{308\text{ K} \times 0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K}}$ = 0.0119 mol; MM = 1.58 g/0.0119 mol = 133 g/mol

133 = 2(12.01) + 3(1.008) + 3 X; X = 35 = Cl

31. 12.8 L NO × $\frac{4\text{ L }NH_3}{6\text{ L NO}}$ = 8.53 L NO

33. 5.85 L SO_2 × $\frac{1\text{ L }Cl_2O}{1\text{ L }SO_2}$ = 5.85 L Cl_2O; 9.00 L Cl_2 × $\frac{1\text{ L }Cl_2O}{2\text{ L }Cl_2}$ = 4.50 L Cl_2O

Cl_2 is limiting; 4.50 L Cl_2O are produced; 9.00 L Cl_2 × $\frac{1\text{ L }SO_2}{2\text{ L }Cl_2}$ = 4.50 L SO_2 react

unreacted SO_2 = 5.85 L - 4.50 L = 1.35 L

35. (a) mol N_2O_5 = $\frac{(1.00\text{ atm})(1.50\text{ L})}{(298\text{ K})(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})}$ = 0.0613

mol H^+ = 0.0613 mol N_2O_5 × 2 mol H^+/1 mol N_2O_5 = 0.123

(b) M = 0.123 mol/0.437 L = 0.281 mol/L

37. $V = (12 \times 11 \times 9)\text{ ft}^3 \times \frac{(12\text{ in})^3}{(1\text{ ft})^3} \times \frac{(2.54\text{ cm})^3}{(1\text{ in})^3} \times \frac{1\text{ L}}{1000\text{ cm}^3} = 3 \times 10^4\text{ L}$

$T = \frac{5}{9}(72 - 32) + 273 = 295\text{ K}$

mol HCN = $\frac{(0.987\text{ atm})(3 \times 10^4\text{ L})}{(295\text{ K})(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})}$ = 1×10^3; mol H^+ = mol HCN = 1×10^3

$V_{H^+} = \frac{1 \times 10^3\text{ mol}}{6.00\text{ mol/L}} = 2 \times 10^2\text{ L}$

39. mol $C_3H_5N_3O_9$ = $\frac{10.00\text{ g}}{227.1\text{ g/mol}}$ = 0.04403

12 mol CO_2 + 6 mol N_2 + 10 mol H_2O + 1 mol O_2 = 29 mol gas/4 mol $C_3H_5N_3O_9$

n_{gas} = (0.04403)(29/4) = 0.3192 mol; $V_{gas} = \frac{(0.3192\text{ mol})(796\text{ K})(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})}{1.45\text{ atm}}$ = 14.4 L

41. $P_{CO_2} = \frac{95}{100} \times 735\text{ mm Hg} = 698\text{ mm Hg}$; $P_{O_2} = \frac{5}{100} \times 735\text{ mm Hg} = 37\text{ mm Hg}$

43. Assume a 100-g sample.

mol CO_2 = (92 g)(1 mol/44.0 g) = 2.1 ; mol NO = (3.6 g)(1 mol/30.0 g) = 0.12

mol SO_2 = (1.2 g)(1 mol/64.1 g) = 0.019 ; mol H_2O = (4.1 g)(1 mol/18.0 g) = 0.23

total number of moles = 2.1 + 0.12 + 0.019 + 0.23 = 2.5

P_{CO_2} = (2.1/2.5)(752 mm Hg) = 6.3 $\times 10^2$ mm Hg; P_{NO} = (0.12/2.5)(752 mm Hg) = 36 mm Hg

P_{SO_2} = (0.23/2.5)(752 mm Hg) = 5.7 mm Hg; P_{H_2O} = (0.23/2.5)(752 mm Hg) = 69 mm Hg

45. total moles = $\dfrac{(0.986\text{ L})(1.00\text{ atm})}{(315\text{ K})(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})}$ = 0.0381

mol dry air = $\dfrac{(1.04\text{ L})(1.00\text{ atm})}{(363\text{ K})(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})}$ = 0.0349

mol H_2O = 0.0381 mol – 0.0349 mol = 0.0032

$P_{H_2O} = \dfrac{(0.0032\text{ mol})(315\text{ K})(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})}{1.00\text{ L}}$ = 0.083 atm = 63 mm Hg

47. mol He = $\dfrac{2.50\times 1.09}{RT} = \dfrac{2.72}{RT}$; mol CO = $\dfrac{2.00\times 0.773}{RT} = \dfrac{1.55}{RT}$; total mol = $\dfrac{2.72}{RT} + \dfrac{1.55}{RT} = \dfrac{4.27}{RT}$

$P = \dfrac{(4.27/RT)(RT)}{(2.50+2.00)\text{ L}}$ = 0.949 atm

49. (a) $2\,C_2H_2(g) + 5\,O_2(g) \rightarrow 4\,CO_2(g) + 2\,H_2O(g)$

(b) mol C_2H_2 = $\dfrac{(7.50\text{ L})(1.00\text{ atm})}{(498\text{ K})(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})}$ = 0.183

4 mol CO_2 + 2 mol H_2O = 6 mol products/2 mol C_2H_2; mol products = (6/2)(0.183 mol) = 0.549 mol

$P_{products} = \dfrac{(0.549\text{ mol})(498\text{ K})(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})}{10.0\text{ L}}$ = 2.25 atm

(c) P_{CO_2} = (4 mol CO_2/6 mol products)(2.25 atm) = 1.50 atm; P_{H_2O} = 2.25 atm - 1.50 atm = 0.75 atm

51. (a) P_{O_2} = (752 - 19.8) mm Hg = 732 mm Hg

(b) mol O_2 = $\dfrac{(732\text{ mm Hg}\times 1\text{ atm/760 mm Hg})(0.125\text{L})}{295\text{ K}\times 0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K}}$ = 0.00497

(c) total moles = $\dfrac{(752\text{ mm Hg}\times 1\text{ atm/760 mm Hg})(0.125\text{L})}{295\text{ K}\times 0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K}}$ = 0.00511

(d) $P_{N_2} = \dfrac{(0.0250/28.02)\text{ mol }(295\text{ K})(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})}{0.125\text{ L}}$ = 0.173 atm = 131 mm Hg

(e) $P_{total} = P_{N_2} + P_{H_2O} + P_{O_2}$ = (732 + 19.8 + 131) mm Hg = 883 mm Hg

53. (a) molar masses: NO = 30 g/mol; Ar = 40 g/mol; N_2 = 28 g/mol; N_2O_5 = 108 g/mol;

$N_2O_5 < Ar < NO < N_2$

(b) $N_2 < NO < Ar < N_2O_5$

55. $\dfrac{\text{rate}_{N_2}}{\text{rate}_{H_2}} = \left(\dfrac{MM_{H_2}}{MM_{N_2}}\right)^{\frac{1}{2}} = (2.02/28.02)^{\frac{1}{2}} = 0.268$

57. (a) lighter

(b) $1.55 = \left(\dfrac{44.1\text{g/mol}}{MM}\right)^{\frac{1}{2}}$; MM = 18.4 g/mol

59. mol NO = 0.0129 mol × $(92.02/30.01)^{\frac{1}{2}}$ = 0.0226

61. $u_{H_2} = \left(\dfrac{3R \times 310}{2.016}\right)^{\frac{1}{2}} = u_{UF_6} = \left(\dfrac{3RT}{352.0}\right)^{\frac{1}{2}}$

Squaring both sides and cancelling $3R$; $310/2.016 = T/352$; $T = 5.41 \times 10^4$ K

63. (a) CO (lower boiling) (b) increase T, decrease P

65. (a) $V_{ideal} = \dfrac{(1.00\text{ mol})(298\text{ K})(0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K})}{200\text{ atm}} = 0.122\text{ L}$

density $\approx \dfrac{16.04\text{ g}}{0.75 \times 0.122\text{ L}} \approx 1.8 \times 10^2$ g/L

(b) $\text{density}_{ideal} = \dfrac{(200\text{ atm})(16.04\text{ g/mol})}{298\text{ K} \times 0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K}} = 1.31 \times 10^2$ g/L; density higher than the ideal value

67. mol air = $\dfrac{(755/760)\text{ atm} \times 1.00\text{ L}}{299\text{ K} \times 0.0821\text{ L}\cdot\text{atm/mol}\cdot\text{K}} = 0.0405$; mol ozone = $(0.0405\text{ mol})(0.60/10^6) = 2.4 \times 10^{-8}$

number of molecules = $(2.4 \times 10^{-8})(6.0 \times 10^{23}) = 1.5 \times 10^{16}$

69. (a) same (b) He (c) He (d) He

71. mol NH_3 = $\dfrac{(1.3\text{ atm})(150.0\text{ L})}{RT} = \dfrac{195}{RT}$; mol O_2 = $\dfrac{(1.5\text{ atm})(150.0\text{ L})}{RT} = \dfrac{225}{RT}$

mol NO from O_2 = $\dfrac{225}{RT}\text{ mol }O_2 \times \dfrac{4\text{ mol NO}}{5\text{ mol }O_2} = 180/RT$

mol NO from NH_3 = $\dfrac{195}{RT}\text{ mol }NH_3 \times \dfrac{1\text{ mol NO}}{1\text{ mol }NH_3} = 195/RT$

Oxygen is the limiting reactant.

73. Density (d) is directly proportional to molar mass at constant P and T. Thus $d^{\frac{1}{2}}$ is inversely proportional to rate.

$$\frac{\text{rate}_{SO_2}}{\text{rate}_{gas}} = \left(\frac{d_{gas}}{d_{SO_2}}\right)^{\frac{1}{2}}; \quad \frac{d_{gas}}{1.31} = \left(\frac{4.48}{6.78}\right)^2; \quad d_{gas} = 0.572 \text{ g/L}$$

$$\frac{\text{rate}_{SO_2}}{\text{rate}_{gas}} = \left(\frac{\text{MM}_{gas}}{\text{MM}_{SO_2}}\right)^{\frac{1}{2}}; \quad \frac{\text{MM}_{gas}}{64.07} = \left(\frac{4.48}{6.78}\right)^2; \quad \text{MM}_{gas} = 28.0 \text{ g/mol}$$

75. Before reaction: P_1, V_1, n_1, 200 K; After reaction: P_1, 2 V_1, n_2, 400 K

$$\frac{P_1 V_1}{n_1(200)} = \frac{P_1(2V_1)}{n_2(400)}; \quad n_1 = n_2; \quad \text{moles of gas before reaction = moles of gas after reaction;}$$

(b) satisifies the equality

77. (a) GT (b) EQ (c) LT (d) GT (e) GT

79. Before: The cylinder has 10 molecules of helium in a confined space, randomly distributed.

(a) After: The space where He molecules are randomly distributed is smaller.

(b) After: The space where He molecules are randomly distributed doubles.

(c) After: The space where He and H_2 molecules are randomly distributed increases by 50%.

81. (a) $P_A = P_B$ (b) $P_A < P_B$

83. (a) $P_A = P_B = 2.0$ atm; $P_A + P_B = 4.0$ atm

(b), (c) reaction occurs: 8 mol X + 4 mol Y $\rightarrow$ 4 mol X_2Y; Flasks contain a total of 4 mol Y and 4 mol X_2Y.

each flask contains 2 ○ and 2 □○□

$P_A = P_B = (1/2)(2.0 \text{ atm}) = 1.0$ atm; $P_A + P_B = 2.0$ atm

Pressure decreases because number of moles decreases.

85. (a) Tank X contains 7 mol CH_4, 1 mol O_2, 3 mol SO_2 = 11 mol

. Tank Y contains 1 mol CH_4, 3 mol O_2, 4 mol SO_2 = 8 mol

Tank Z contains 4 mol CH_4, 2 mol O_2, 1 mol SO_2 = 7 mol

Pressure highest in Tank X

(b) Tank X: $P_{SO_2} = (3/11)P$; Tank Y: $P_{SO_2} = (4/8)P$; Tank Z: $P_{SO_2} = (1/7)P$

Partial pressure of SO_2 highest in Tank Y.

(c) Tank X: 112 g CH_4, 32 g O_2, 192 g SO_2
Tank Y: 16 g CH_4, 96 g O_2, 256 g SO_2
Tank Z: 64 g CH_4, 64 g O_2, 64 g SO_2
Tank Z contains the same mass of each gas.

(d) Tank Y

86. 25.0 mm Hg at 40°C 27.3 mm Hg at 70°C 29.7 mm Hg at 100°C
Values are much lower than observed vapor pressures. In vapor, n increases as well as T.

87. $1.12 \times 10^3 \text{ m/s} = \left(\frac{3(8.31 \times 10^3)(288)}{\text{MM}}\right)^{\frac{1}{2}}$; $\text{MM} = \frac{3(8.31 \times 10^3)(288)}{(1.12 \times 10^3)^2} = 5.72 \text{ g/mol}$
He (MM = 4.003 g/mol) and H_2 (mm = 2.016 g/mol) are not found in the earth's atmosphere;
Ar (MM = 39.95 g/mol) is.

88. distance for NH_3/distance for HCl = $(\text{MM}_{HCl}/\text{MM}_{NH_3})^{\frac{1}{2}} = (36.46/17.03)^{\frac{1}{2}} = 1.463$
$(1.000 + 1.463)d_{HCl} = 5.0$ ft; $d_{HCl} = 2.0$ ft; 3.0 ft from NH_3 end

89. 1.8°R = K: $R = 0.0821 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times \frac{1 \text{ K}}{1.8°\text{R}} = 0.0456 \text{ L·atm/mol·°R}$

90. $\text{mol } H_2 = \frac{(755/760) \text{ atm} \times 0.147 \text{ L}}{(298 \text{ K})(0.0821 \text{ L} \cdot \text{atm/mol} \cdot \text{K})} = 5.97 \times 10^{-3}$
Let x = mass Al; $0.00597 = \frac{3x/2}{26.98} + \frac{0.2500 - x}{65.39}$; $x = 0.0533$ g
mass Zn = 2.500 - 0.0533 = 0.197 g; $\% \text{ Zn} = \frac{0.197}{0.250} \times 100\% = 78.8\%$

91. $\text{mass air} = \frac{(758/760) \text{ atm} \times V \times 29.0 \text{ g/mol}}{(295 \text{ K})(0.0821 \text{ L} \cdot \text{atm/mol} \cdot \text{K})} = 1.19V$; $\text{mass } H_2 = \frac{(758/760) \text{ atm} \times V \times 2.016 \text{ g/mol}}{(295 \text{ K})(0.0821 \text{ L} \cdot \text{atm/mol} \cdot \text{K})} = 0.0830V$
$1.19\,V = (1.68 \times 10^5) + 0.08V$; $V = 1.51 \times 10^5 \text{ L} = 151 \text{ m}^3$
$151 \text{ m}^3 = 4\pi r^3/3$; $r = 3.30$ m; diameter = 2(3.30 m) = 6.60 m

92. $P_2 = P_1 \times \frac{T_2}{T_1} \times \frac{n_2}{n_1}$; $n_1 = 3.00$ mol; $n_2 = (1.76 + 0.12 + 0.24)\text{mol} = 2.12$ mol
$P_2 = (0.950 \text{ atm}) \times \frac{398}{298} \times \frac{2.12}{3.00} = 0.897 \text{ atm}$

93. $V_a = n_aRT/P$; $V_{tot} = n_{tot}RT/P$; $V_a/V = n_a/n_{tot} = X_a$
$n_a/n_{tot} \neq m_a/m_{tot}$ because molar masses differ.